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Solder ball bumper SB/sup 2/-a flexible manufacturing 3-dimensional sensor and microsystem packages

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Abstract:
A novel high speed **solder** deposition system for microelectronic devices has be developed by Pac Tech GmbH. With this fully automatic system, the high speed **ball** bumper (SB/sup 2/), preformed **solder balls** are placed at pre-programm **positions** and are reflowed by a laser pulse in a single step. The use of flux or reflow is not necessary. The system design fits a broad range of applications. D low heat input during **solder** deposition, and the fact that additional componen is not required, this method is especially interesting for temperature sensitive d Besides bumping processes on single dice or at wafer level, **solder balls** for IC such as /spl mu/-BGAs, BGAs and chip size packages can be placed and reflowe applications include **solder** deposition for PCBs and interconnection of 3D auto sensor chip packages. With small modifications, the SB/sup 2/ can process **sold** with diameters from 100 /spl mu/m up to 1 mm. A singulation unit separates t from the bulk by means of a rotating cavity disk. Using a pneumatic pulse, the transported from the cavity down to the capillary tip. The **solder ball** reflow is with a laser beam that passes through a glass fiber into the capillary directly ab placed **ball**. During laser pulsing, nitrogen prevents oxidation of the liquid **sold** SB/sup 2/ also provides great flexibility for microelectronic device repair. The s be used to realise a repair station attached to the normal process flow. It allow selective removal of defective **solder** bumps and renewed **solder** attach to the pads.

Index Terms:
reflow **soldering**; SB/sup 2/ **solder ball** bumper; flexible manufacturing tool; packages; 3D microsystem packages; high speed **solder** deposition system; microelectronic devices; **solder ball** bumper; preformed **solder ball** placemen pre-programmed bond **positions**; laser pulse reflow; heat input; **solder** depos temperature sensitive devices; bumping processes; wafer level bumping; **solde** IC packages; micro-BGAs; BGAs; chip size packages; PCBs; 3D automotive sen package interconnection; **solder ball** diameter; singulation unit; rotating cavit pneumatic pulse **ball** transport; capillary tip; **solder ball** reflow; glass fiber; la pulsing; nitrogen atmosphere; liquid **solder** oxidation prevention; microelectro repair; repair station; process flow; selective defective **solder** bump removal; **solder** attach; contact pads; 100 micron to 1 mm

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Solder Ball Bumper SB² - A flexible manufacturing tool for 3-dimensional sensor and microsystem packages

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Abstract

A novel high speed system for solder deposition on microelectronic devices has been developed by PacTech GmbH. With this fully automatic system, called High Speed Solder Ball Bumper (SB²), preformed solder balls are placed at pre-programmed bond positions and are reflowed by means of a laser pulse in one step. The use of flux or a second reflow is not necessary.

The system design fits to a broad range of applications. Due to the small input of thermal heat during solder deposition, as well as an additional heating of the parts is not required, this method is especially interesting for temperature sensitive devices. Besides bumping processes on single dice or wafer level, solder balls for miscellaneous microelectronic packages, like μ-BGAs, BGAs and Chip Size Packages can be placed and reflowed. Other applications include solder deposition for printed circuit boards and the interconnection of 3D packages for automotive sensored chips.

With small modifications the High Speed SB² can process solder balls with diameters from 100 μm up to 1 mm. A singulation unit separates the balls from the bulk by means of a rotating cavity disk. Using a pneumatic pulse, the ball is transported from the cavity down to the tip of the capillary. The reflow of the solder ball is performed with a laser beam that passes through a glass fiber into the capillary directly above the placed ball. During laser pulsing nitrogen prevents the oxidation of the liquid solder.

The SB² also provides great flexibility for the repair of microelectronic devices. The system can be utilised to realise a repair station attached to the normal process flow. It allows a selective removal of defective solder bumps and a renewed solder attach to the contact pads.

Introduction

The race in microelectronics towards higher integration densities of different functions demands innovative tools and production techniques, especially in the field of packaging and interconnection.

A novel technology has been realized in cooperation by Fraunhofer IZM and PacTech GmbH. The principle operation is based on the placement and controlled laser reflow of preformed solder balls.

Commonly standard processes are aimed at a determined product and also demand a cost-intensive equipment, which is profitable only by a high volume production. Therefore, the overall goal was to develop a flexible datadriven system that enables a low cost processing of a wide range of microelectronic devices without using specific tools or equipment. A basic version of the solder ball bumping system was recently established on the market /1/. The next generation of the SBB equipment, a High Speed Version is presented in this paper.

The capabilities and benefits of the Solder Ball Bumping technology are:

- The system design enables the processing of a broad range of materials: all solder alloys, pure metals, and coated as well as uncoated polymer balls can be processed.
- The method is applicable on all wettable pad metallizations.
- The solder ball placement and reflow is performed in one step. No additional process steps are required.
- Due to the one step processing the datadriven system enables a rapid prototyping, as well as a low cost production of low and medium volume.
- The application of the solder is a flux-free process and a second reflow is not required. Therefore, the entire process is very environmentally friendly.
- With few modifications of the bondhead solder balls with diameters from 100 μm up to 1 mm can be processed.

- During ball placement and reflow procedure no mechanical load occurs on the devices, because the capillary does not touch the contact pads.
- Due to the small and very localized input of thermal heat during solder reflow by using a laser, as well as an additional heating of the devices is not required, the thermal stress of the devices is minimized.
- The process works without substrate specific tools, that means:
  - A high flexibility regarding different microelectronic devices.
  - Fast adaptation to changed layouts of chips and wafers due to pad position programming.
  - Short setup times and distinctive lower costs in case of production change.

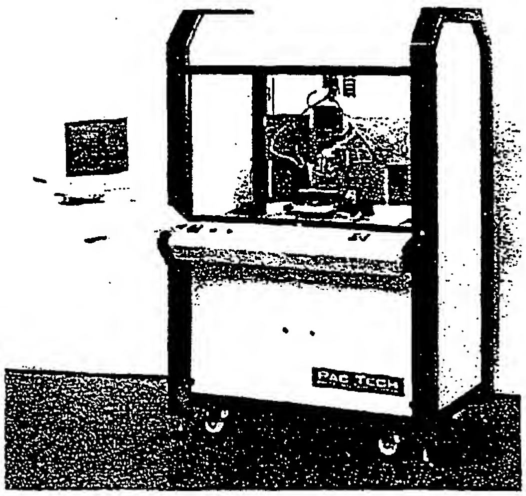

Figure 1: High Speed SBB (front enclosure removed)

Machine Concept

The High Speed SBB is a compact system with all components (except for the laser) integrated into the chassis. The main subsystems include: laser class 1 enclosure, bond head with singulation unit (mounted on Z stage), X,Y-stages with 6" wafer chuck, system control unit, visualization system and a Nd:YAG-Laser.

An overall view of the High Speed Solder Ball Bumper is shown in Figure 1.

The entire system is specified as laser class 1 product. Due to the laser class 1 enclosure, no laser radiation is emitted by the system. If the enclosure is opened by an operator the interlock system ensures, that a pulsing of the laser is avoided. Therefore, no specific laser safety area for operation is required.

In the bond head all important components like loading station, singulation unit, capillary for positioning, fiber conduction system for the supply with laser energy and different sensors are integrated (Figure 2).

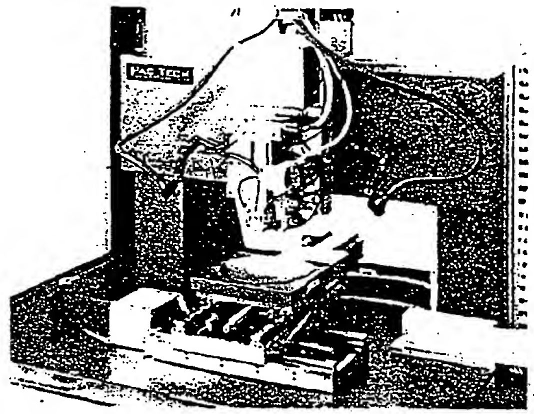

Figure 2: Bond head

In Figure 3 the principal way of operation is shown. While the bond head drives the capillary exactly above the pad position, solder balls from the loading station are singulated through a singulation unit simultaneously.

Using a pneumatic pulse, the ball is transported from the singulation unit down to the tip of the capillary. The reflow of the solder ball is performed by a laser beam which passes through a glass fiber into the capillary directly above the placed ball.

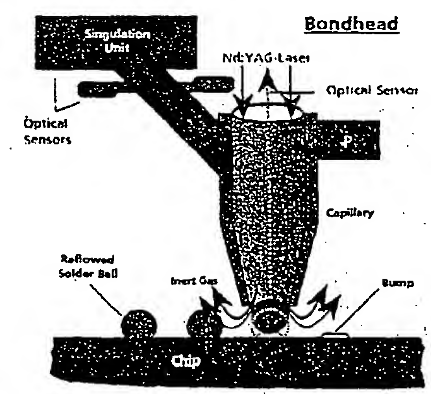

Figure 3: Principle set up

During laser pulsing inert gas (nitrogen) pours out of the capillary. The nitrogen acts as a shielding atmosphere, allowing the reflow of the ball to a smooth hemispherical bump on the pad. The complete cycle (singulation, transport and reflow of the solder ball) is controlled by different sensors.

The ball singulation is achieved with a rotating conveying disc which has cavities to accept single balls. The disc is adapted to the respective ball diameter.
By a defined rotation of the disc, the balls are loaded into the cavities individually at the loading station. By further rotation of the disc, a ball is brought to its eject position and is fired down onto the bond pad with inert gas.
After the ejection the ball is fed with precision to the bond pad by means of a capillary. The minimum ball pitch is determined by the exterior outline of the capillary.
The inner pressure in the capillary is measured with a sensor, and changes in pressure ascertain whether the ball has reached the pad. The pressure data is used by the control system to activate the laser and for synchronization of the process.
The overall failure of the process control using a pressure sensor is about 90 ppm. A further yield improvement can be reached through optical real time process control. Therefore, the integration of a vision system for in-situ control of the bumping process is a focus of our ongoing research efforts.
The computer-controlled bond head allows either automatic or manual processing. In the automatic mode processing is possible at frequencies up to 7 Hz (= 25.000 balls/hour). Bumping positions can both be programmed by manual teach-in or imported as datafiles; in one data file up to 100.000 positions can be saved.
The adaptation of the bond head to different solder ball diameters can easily be done by changing singulation disc and capillary.
The small and compact design of the bond head allows the performance of bumping processes in a single work station as well as the integration of the bond head into an existing production line.

Solder Ball Bumping for 3D- Sensors and interconnects

A series of applications in automotive industry require a vertical assembly of chips and sensors. The SB² is a suitable technique for providing the solder and in the same operation.
For implementation of the vertical chip process into manufacturing environment following process flow is possible:

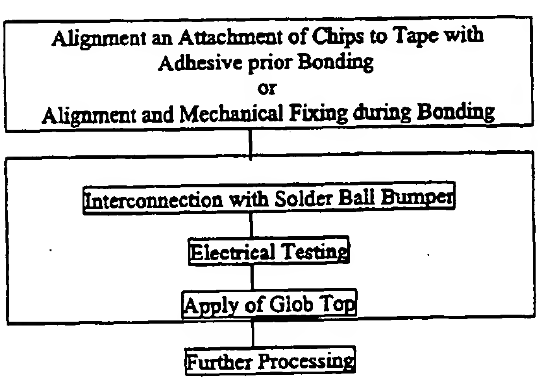

Fig. 4a: Possible Process Flow

Alignment and attachment of the chips to tape with adhesive prior the bonding process would reduce the over all cycle time per part significantly, because the two processes can run simultaneously. The process steps electrical testing and glob top apply can also be integrated in the interconnection process.

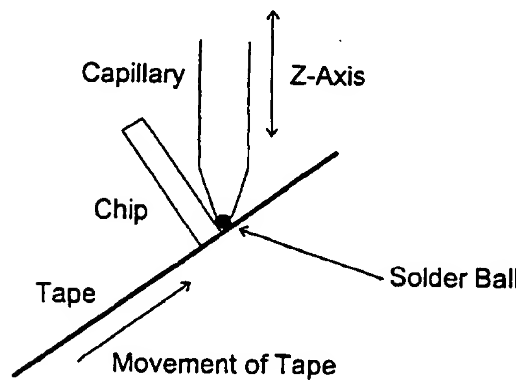

Fig. 4b: Principle Setup

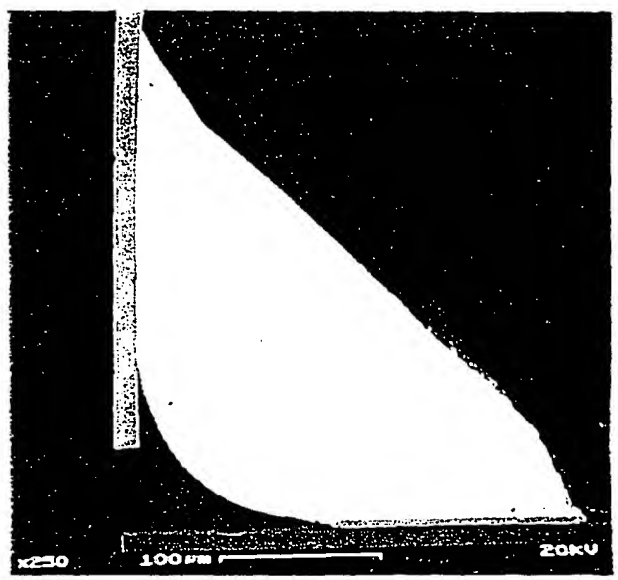

Fig. 5: Cross Section of Solder Joint in a vertical Chip (Sensor) substrate interconnection

Solder Ball Bumping for Flip Chip Assembly

In the next few years flip chip technology will be a wide spread application in automotive, consumer and telecommunication industries due to cost reduction, increased package density and improved reliability.

An important impact for the breakthrough will be the implementation of low cost bumping processes like the electroless Ni plating process which generates a wettable metallization on the chip I/O's. The Ni metallization is plated in a fully wet chemical process. An additional gold flash ensures a protection against oxidation and improves the wettability. Due to the maskless and selective autocatalytic nickel deposition directly on Al pads, expensive equipment for metal sputtering and photolithography is not necessary. This economical process was developed at TUB/IZM and transferred to PacTech. The details of the Ni bumping process are described in /2,3/.

In Figure 4 placed and reflowed solder balls (63/37 PbSn; diameter: 125µm) on a Ni metallization are shown. During the laser pulse the surface tension of the liquid solder leads to self-adjusting and to entire wetting of the gold-plated nickel metallization. In order to specify failure mechanisms and to optimize process parameters shear tests of single bumps were performed during process evaluation. Typical laser parameters are a power of 6 to 8 Watts and a pulse width lower than 10 ms. During pulsing inert gas (N_2) pours out of the capillary and prevents the oxidation of the liquid solder.

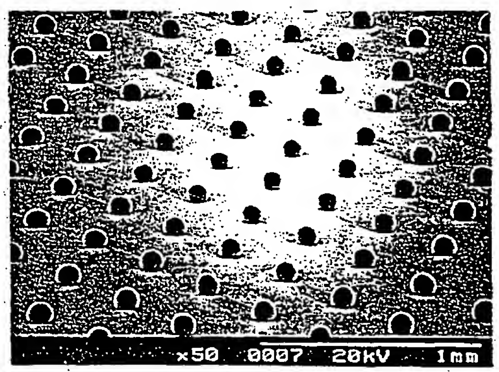

Figure : Placed and reflowed solder balls on chip site

Using optimal laser parameters shear force causes a material separation only in the solder bulk. Failure of the solder/nickel and nickel/aluminum interfaces was never observed.

The other possibility is the solder application on substrate site. An example is given in Figure 5 where the solder balls are placed and reflowed on the contact pads of a fine line printed circuit board. The contact pads have a size of 100 µm x 100 µm and a pitch of 200 µm.

Remarkable on the combination of the electroless nickel plating process and the solder deposition with the High Speed SBB is, that the entire bumping process requires no device specific tools or equipment, like masks or stencils.

Solder Ball Deposition on Chip-Size Packages

Various Chip-Size/Scale Packages (CSP's) are in development worldwide.

A low cost solution of a CSP presented here is based on the interconnection of the bare IC to a one metal layer flexible interposer using a Laser FPC Bonder. The principle of the Fiber Push Connection (FPC) method is described elsewhere /6,7,8/.

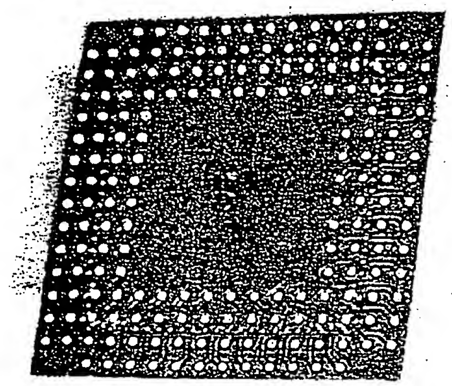

Figure 7: Flex Interposer with solder balls for the CSP attach to the board

Mechanical stability is incorporated in the CSP by using a low stress, low viscosity adhesive dispensed between chip and substrate prior the connection is established. A performance advantage for the SMD soldering is added by solder bumping the CSP using the High Speed SBB. Due to the datadriven ball placement, different types of CSP can be easily accommodated. The package obtained is fully surface mount compatible, allowing for a wide process window /9/.

Figure 7 shows the flexible interposer with the solder balls (300 µm, 63/37 PbSn) attached to the bottomside of the Chip Size Package.

Figure 8 shows a cross section of a Chip-Size Package. Detailed information on this low cost package solution is given by Azdasht et al. /10/.

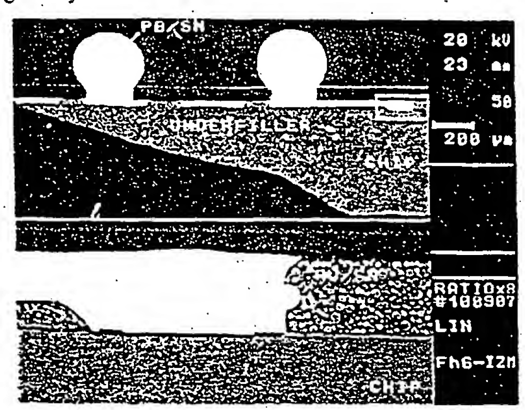

Figure 8: Cross Section of a Chip-Size Package

Solder Ball Deposition on BGA's

Another application of the Solder Ball Bumping technology is the solder ball placement and laser reflow on Ball Grid Arrays. BGA's are a often preferred choice of packaging for applications driven by higher pincount and thermal as well as electrical performance. The major applications are computers and portable communications.

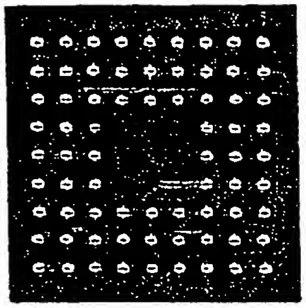

Figure 9: 780µm diameter balls (63/37 PbSn) placed and reflowed on a BGA

In Figure 10 a test BGA with 78 I/O's is shown. The pad sizes of this device are 600 µm in diameter by a pitch of 1.5 mm.
This FR4 BGA package uses a eutectic 63/37 PbSn solder. The application of high melting 95/5 PbSn solder balls on BGA's is also done successfully.

The SBB as Repair Station for Microelectronic Devices

The system can be utilized to realize a repair station. It allows a selective removal of defective solder bumps and a renewed soldering of the pads.
The repair procedure is as follows:
If necessary, in a first step the defective solder bump is removed by means of laser reflow and vacuum. For this a second capillary with fiber conduction system must be incorporated in the bondhead.
The removed solder is sucked off through the capillary and is stored in a small waste disposal. A nitrogen flow prevents the oxidation of the solder cap which remains on the pad (Figure 10).

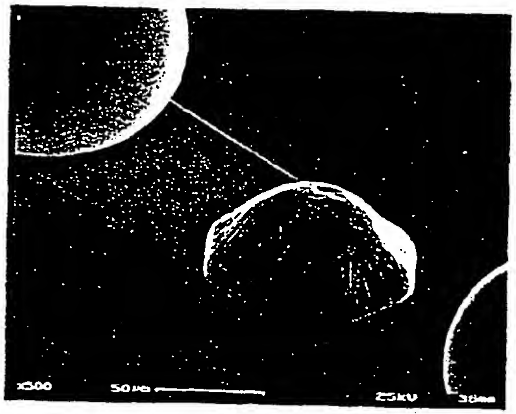

Figure 10: Removal of a defective solder bump

In the second step a new solder bump is applied. The small oxide free solder cap enables a entire wetting of the new solder bump on the reworked contact pad.
The whole procedure can be done fully automatically by the vision control system.
Due to the very localized input of thermal heat by using a laser, as well as an additional heating of the parts is not required, the thermal stress of the devices is minimized during repair procedure.

Cost modeling

In order to show the competitiveness of the solder ball bumping process a modeling following the total cost of ownership (TCO) method was made /11/.

A TCO calculation includes all relevant costs, like acquisition, use and maintenance. The most important factors of the analysis are fixed costs, recurring costs, utilization and yield. The modeling was made in comparison to solder paste stencil printing which is known as a low cost process for high volume production in the electronics manufacturing industry. The example data used for the cost modeling are summarized in Table 1.

Wafer	
Size	6"
Wafer yield	0.7
Chip count	164
Total I/O count	19680

Chip	
Size [mm]	10 x 10
Pad area [mm]	0.1 x 0.1
I/O count	120

Table 1: Wafer data used for cost modeling

While the results (Figure 11) show that for a processing of more than 35.000 wafers per year stencil printing is more economical, for a low up to a medium volume production the costs for the solder ball bumping process are distinctively lower.
It can be resumed, that the Solder Ball Bumping technology is a competitive method for production environment, especially if high flexibility and fast turnover cycles are required.

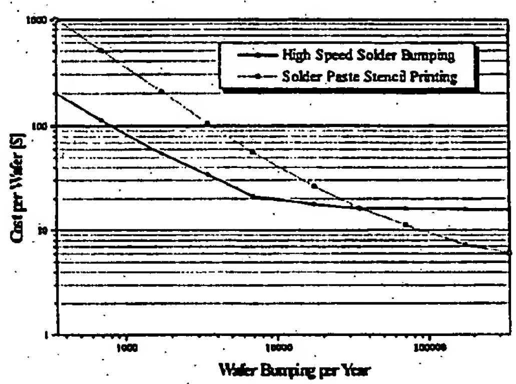

Figure 11: TCO modeling of the solder ball bumping process compared to solder paste stencil printing

Conclusions

The High Speed Solder Ball Bumper is a novel, flexible bumping system that fits to a broad range of applications for microelectronics manufacturing industry.

Due to the one step processing the datadriven system enables a rapid prototyping, as well as a low cost production of low and medium volume. Besides bumping processes on chip and wafer level, solder balls of different sizes for μ-BGAs, BGAs, Chip Size Packages and various microelectronic devices can be placed and reflowed. Other main advantages are the flux free processing and that device specific tools or equipment are not required.
Another application addresses the use of this system as repair station for microelectronic products.

Acknowledgements

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